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# Evaluation of Wetting Front Detector on Water Productivity and Its Savings Under Pepper Production at Dugda District, East Shoa Zone of Oromia Region

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**Abstract**
The limitation in water availability and also salinity and waterlogging related to over application of irrigation water resulted in low crop water productivity, which obliges to adopt alternative water management techniques. The work compared a simple on-farm water optimization technology called Wetting Front Detector (WFD) against computer program to estimate Crop Water Requirement (CWR) and farmers practice (FP). A field experiment was designed in Randomized Complete Block Design, replicated six times on farmers' fields. Results were compared on the basis of application, distribution, storage and water use efficiencies, and water productivity. The results illustrate that there was a significant difference between the water used in the CWR, WFD and FP. In comparison with FP, CWR saved irrigation water by 37% under pepper field. The WFD technology also saved the irrigation water by about 16% than the farmer method. The differences between the water optimization techniques can be accounted for by to differences in the efficiencies of application ($E_a$), storage ($E_r$) and irrigation water use which vary considerably from one type of irrigation water management to another at $p<0.05$. Generally, CWR technique is more efficient ($E_a$ is 66.76%), followed by the WFD technique ($E_a$ is 62.32%) and farmer practice ($E_a$ is 55.74%) under pepper. On the basis of these values, the water saved by the CWR technique could irrigate 16.5% and the WFD 6-8% more area than the FP. Implicitly better crop production, also less competition between head and tail irrigators. The mean IWUE of CWR, WFD and FP were 3.67, 3.08 and 1.52. Based on this study, CWR technique appears to be a promising alternative for water saving without negligible trade-off in yield. The CWR had an $E_r$ of 66.42% which can be beneficially used by the crops while the WFD of 50.85%. As a result, yield of the crop from the CWR exceeds both techniques as it can provide sufficient amount of water for plants at their root zones. Considerable amount of water in FP is lost to Deep Percolation ($D_p$) and this has environmental and economic implications. Although many indicators confirm the importance of CWR approach, its practicality at farmers level is questioning as it is computer based. Thus, WFD would be an important tool to be considered to improve the current on farm water optimization by smallholder irrigators.
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## 1. Introduction

Population of Ethiopia is growing at an alarming rate of 2.89% (CIA World Factbook, last assessed by August 2016) while the resources they are expanding on are limited, and the production itself is not at the rate the population is growing. Water for agriculture is amongst the limiting resources not to feed the growing population with more diversified diets. If rainfall is adequate to meet the total water requirements of the crop and occurs at the time when the crops need it, irrigation may not be as such required and crop production can be rain-fed (Arora, 2004). In Ethiopia where the climate change exposes the nation to frequent drought, such ideal conditions are however rare where water availability for crop production is highly erratic both spatially and temporally (Seleshi *et al*., 2007). Efforts to ensure food self-sufficiency at household level require efficient use of irrigation water and appropriate water application techniques. The farmers' irrigation method is aiming at supplying sufficient water to crops to avoid water stress during the whole growing stage, so as to achieve maximum yield (Doorenbos and Pruitt, 1992). However, the limitation in water availability and, salinity or toxicity related to over irrigation obliges to adopt alternative water management techniques (Lorite *et al*., 2007).

Among the four types of irrigation – LEPA, drip, sprinkler and surface, (flood, basin, border and furrows) – sprinkler, drip and LEPA methods are known to be efficient in maximizing water utilization; but their initial investment cost is often prohibitive and not affordable by the developing countries like Ethiopia. Under such conditions, least initial investment and yet less precise irrigation systems have to be considered. As a result, furrow irrigation method is the most widely used, and is particularly suitable for irrigating row crops.

Wetting Front Detector (WFD) and CROPWAT based Crop Water Requirement (CWR) are amongst the very useful and popular techniques through which optimization of irrigation water. These techniques are required to be evaluated for their efficiency as compared to farmer's practice on the basis of observation of crop condition. CROPWAT based CWR are calculated by considering the readily available soil water content concept. The CWR were simulated by a soil water balance based on the weather conditions, soil and crop characteristics (Allen *et al*., 1998).

The general objective of this study was to ascertain the amount of water likely to be saved and evaluating the crop and water productivity by using different water optimization tools. The specific objectives of the study include:

(i) To determine the water productivity for pepper crop,
(ii) To quantify the amount of water saved under different water optimization techniques

## 2. Materials and methods

### 2.1. Description of the Study Area

The study was conducted at Dugda district, East Shoa zone of Oromia National Regional State. Meki town is the Dugda capital, located 134 km away from the capital of Ethiopia, Addis Ababa to the south east direction. Dugda is found between $38^{0}32^{'}00^{''}$E to $38^{0}07^{'}05^{''}$E and $8^{0}02^{'}50^{''}$N to $8^{0}23^{'}00^{''}$N. Its mean altitude is 1662 meter above sea level.

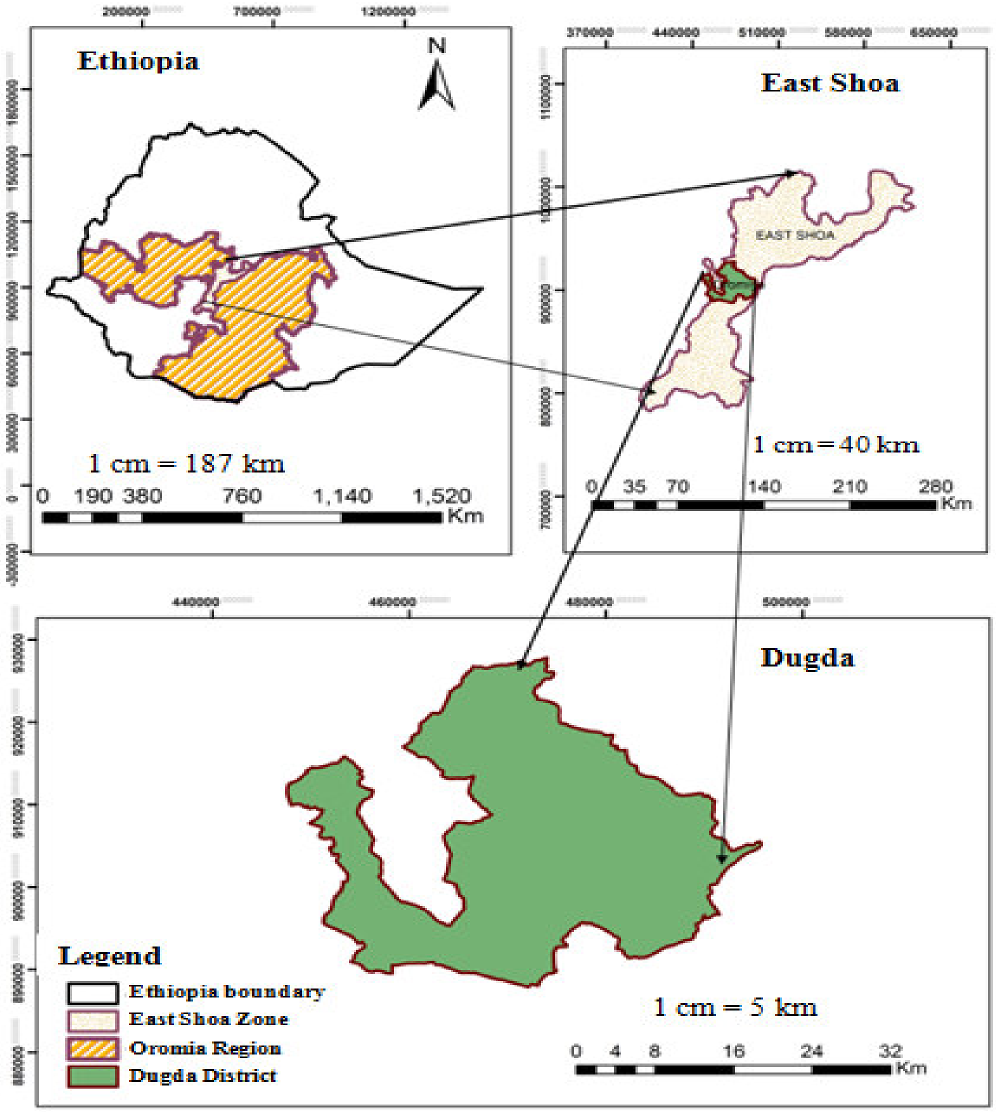


Figure 1. Location map of the study area

Weather data – maximum and minimum temperatures, wind speed, precipitation, sunshine hours and relative humidity – of about 22 years of a nearby station were obtained from National Meteorological Services Agency. The Dugda climate is mild, and generally warm and temperate. The summer is much rainier than the winter. The average annual temperature is 21.1°C. On an average, about 694.1 mm of precipitation falls annually. Precipitation is the lowest in December (5.5 mm) while the highest occurs in July (173.6 mm). The difference in precipitation between the driest and wettest months is 168.1 mm. At an average temperature of 29.6°C, April is the hottest month of the year. The lowest average temperatures (11.3°C) in the year occur in December. The average variation in temperatures throughout the year is 13.5°C (Figure 2).

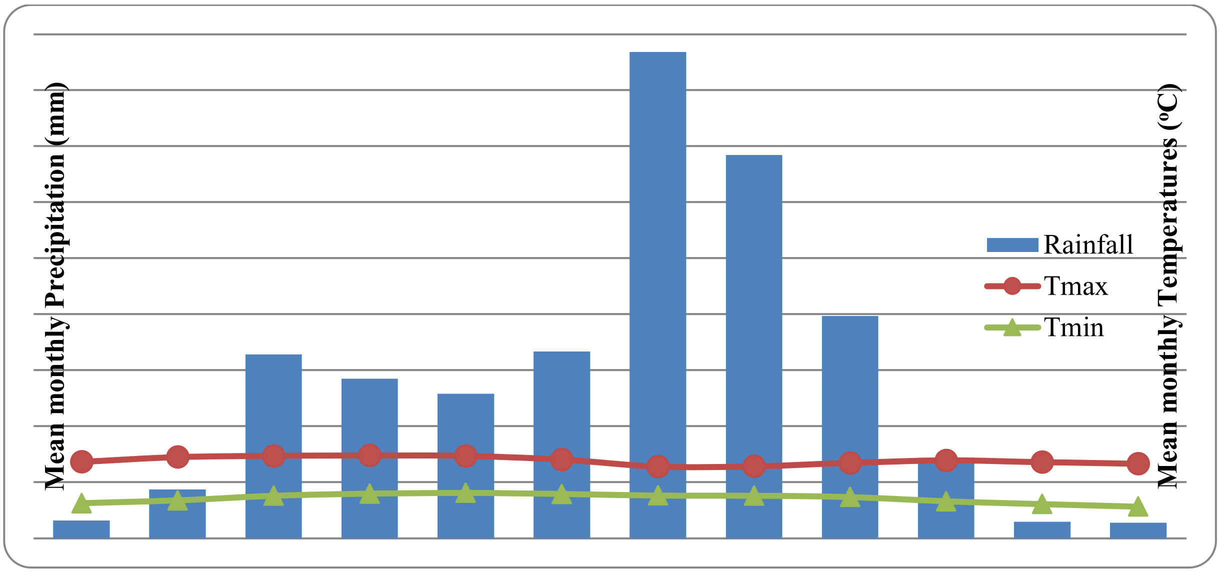


Figure 2. Dugda area weather condition

The major soil class is generally sandy loam, had moderately high infiltration rate and low water storage capacity. As a result, they need frequent but small amount of irrigation applications (Scherer *et al*., 1996).

Dugda district experiences frequent drought, and hence moisture stress is the bounding problem for their agricultural production. Thus, it is one of the intensively irrigated areas in Ethiopia. Crops grown include pepper, tomato, onion, potato, shallot, haricot beans, sweet potato, papaya, wheat, maize and teff. Farmers grow crops three times a year: two during the dry season (September to May) by conventional furrow irrigation, the other during the rainy season (June–September) using rainfall and irrigation (MoFED, 2006).

Primary and Secondary Data Collection: Weather data were obtained from National (Ethiopian) Meteorological Service Agency. Soil infiltration rate and its physico-chemical properties, irrigation efficiency parameters and yield of the crop were directly measured on the field.

## 2.2. Experimental Design and Layout

Among many techniques used to evaluate need of irrigation water by a crop, wetting front detector and CROPWAT based crop water requirements were evaluated along with farmer's practice on the basis of observation of crops production. Each experimental plot had a common dimension of 10 m X 5 m. Each complete set of treatment was replicated on farmers' fields by RCBD design. The 6 plots from where yields collected were laid out as seen in Figure 3.

**Description of the treatments:**

$T_1$ = farmers practice

$T_2$ = CROPWAT based crop water requirement

$T_3$ = Wetting Front Detector

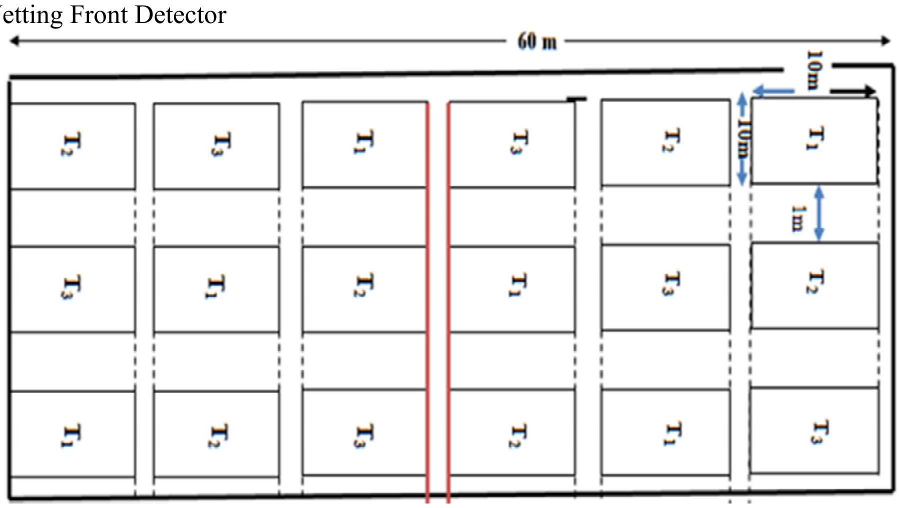


Figure 3. Field layout and treatment arrangement

### 2.3. Seedling Preparation and Transplanting

*Brother Hybrid* Pepper variety was obtained from commercial seed growing enterprise –Flora Vetch greenhouse – from where it was directly transplanted after 45 days. It was transplanted onto the farmer's fields by 80 cm x 30 cm spacing between rows and plants respectively.

### 2.4. Analysis of Soil Physico-chemical Properties

The soil was characterized in terms of its texture, organic carbon, bulk density, water retention at FC and PWP and pH. Composite soil samples were collected from the experimental field at depths of two intervals viz. 30 cm increments (0 – 30 cm and 30 – 60 cm) up to 60 cm depth from the surface diagonally. Soil texture was determined using pipette method (Nelson and Sommers, 1996). Organic carbon content was determined by titration method using chromic acid (potassium dichromate + $H_2SO4$) digestion method. Finally, conversion of organic carbon to OM was, therefore, obtained by multiplying percentage organic carbon by 1.724 as described in (Walkley and Black, 1934).

Moisture contents at field capacity and permanent wilting point were measured using a pressure plate apparatus at Ethiopian National Soil Laboratory by applying pressures at 0.33 and 15 bars, respectively. The moisture content of the soil samples on volume basis were determined on calculation basis. pH was measured in 1:1 soil:water mixture by using a pH meter. Distilled water was used as a liquid in the mixture.

The soil bulk was determined by core method from undisturbed soil samples. Soil bulk-density data was taken by core sampler 0-60 cm, oven dried for 24 hrs at $105^0$C – at which constant weight is observed – and weighed for dry density using the formula:

$$\rho b = \frac{W_d}{V_C} \qquad \textbf{(1)}$$

where: ρb = bulk density (g/cm$^3$), $W_d$ = weight of dry soil (g), $V_c$ = core sampler volume (cm$^3$)

**Infiltration Rate**: Double ring infiltrometer method was used to identify the basic infiltration rate of the field. Ring infiltrometers were operated by inserting two rings (30 cm and 60 cm diameters were used), ponding one known head of water inside the rings, and measuring the rate of water flow out of the rings into the unsaturated porous medium.

Test was started by pouring water into the ring. The water was added to the space between the two rings to the same depth at the same time quickly. The water in the outer ring is to prevent a lateral spread of water from the inner ring. Water depth in the inner ring was frequently noted by measuring rod, and water was added to bring the level back to approximately the original level at the start of the test. Similarly, the water level inside the outer ring was maintained. The test continued until the drop in water level was the same over the same time interval.

### 2.5. Materials Used

Parshall flume for discharge measurement, soil auger and core sampler for soil sampling (disturbed and undisturbed), plastic bag for composite soil sample collection, double ring infiltrometer for infiltration rate test, measuring tape and water level for field layout and furrow design, wetting front detector to detect irrigation water, GPS, pepper seeds, chemicals and fertilizers were used to conduct the field experiment.

### 2.6. Working with Wetting Front Detectors

Wetting front detectors (WFD) are the mechanical version having a float visible at the surface to provide the signal that a wetting front had reached the prescribed depth. It was conceived and developed against the background of poor irrigation water management technologies. Essentially it reframed the age old irrigation scheduling question from 'when to turn the water on' to 'when to turn it off'. The focus of soil based monitoring had been on specifying refill points, i.e. how dry the soil could be allowed to get without affecting production of the crop (Stirzaker, 2003). A pair of detectors is installed at different depths: one buried at $1/3^{rd}$ cm depth – indicating water entering the root zone – and the other at $2/3^{rd}$ cm depth – possibly warning of over irrigation (Stirzaker *et al.*, 2005). They were installed at the three-fourth of the furrow length from the tertiary canal. Detectors were positioned half under the furrow and half under the bed with the extension tube rising through the shoulder of the bed. The shorter in length have yellow indicator on its top, while the longer in length is assigned red indicator which are visible to the irrigator (Stirzaker *et al.*, 2005).

Irrigation water was applied following the response of the tools. Specifically, adjusting the irrigation water to the response of yellow flag (shallow detector) indicate adequate irrigation; the red flag (deep detector) ideally remain down implying irrigation water was not reached the depth the deep detector installed. The irrigation water was 'turned on' when the yellow flag returns down, and it was 'turned off' as far as the shallow detector stayed up.

### 2.7. Farmer Irrigation Method of the Study Area

'When' and 'how much to apply' irrigation water for different farmers were different. As a result, over irrigation in some part and shortage in other may happen. It has economic and environmental implications which normally reflected on crop water productivities. In order to overcome such disparity, irrigation water was applied by a common, experienced farmer during all growing season in order to keep uniformity for all the replications within the treatment for the crop in this study. Although it is impossible to homogenize within the farmer irrigation practice, it was kept to its minimum.

### 2.8. Determination of Soil Moisture Content

Soil samples from 2 depths (0-30 and 30-60 cm) were taken from respective plots and weighed ($w_w$), dried at 105$^0$C for 24 hours and reweighed after drying ($w_d$). Moisture content on mass basis ($\theta_w$) then estimated by using the following expression (Walker, 1989):

$$\theta_w = 100(w_w - w_d) \div w_d \tag{2}$$

The volumetric moisture content ($\theta_v$) in % was then computed from the moisture content on mass basis (%) by multiplying the bulk density ($\rho_d$) in gm/cm$^3$ divided by the specific weight of water gm/cm$^3$ which can be assumed to have a value of unity (equation 3):

$$\theta_v = \theta_w \times \frac{\rho_b}{\rho_w} \times 100 \tag{3}$$

### 2.9. Amount and Duration of Water Application

When to apply irrigation water, flow-rate, and duration of irrigation applications are the three essential elements that should be emphasized by an irrigator. The duration of an irrigation delivery to one farm must be chosen in a way that meets the irrigation water needs of the crops. Duration of irrigation water application for an area of crop land is computed from depth of water needed to satisfy the crop water requirement at the time, the flow rate and the area to be irrigated. For a field irrigated by furrows, the duration of water application for the field was divided for the number of furrows of the plot, and the duration of water application for the furrows then controlled by the stopwatch for uniform application.

The amount of water needed to compensate the amount of water lost through evapotranspiration ($ET_c$) requires reference evapotranspiration ($ET_0$) and crop coefficient ($K_c$). Periodic reference crop evapotranspiration ($ET_0$) for each day of climatic record was calculated based on the modified FAO Penman-Monteith equation using FAO CROPWAT software version 8. The FAO Penman-Monteith method uses standard climatic records of solar radiation (sunshine), air temperature, humidity and wind speed for daily, weekly and monthly calculations and calculates $ET_o$ as Allen *et al.* (1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{4}$$

where

$R_n$ = net radiation at the crop surface (MJ m$^2$ day$^{-1}$), G = soil heat flux density (MJ m$^{-2}$day$^{-1}$), T = mean daily air temperature at 2 m height ($^0$C), $U_2$ = wind speed at 2 m height (ms$^{-1}$), $e_s$ = saturation vapour pressure (KPa), $e_a$ = actual vapour pressure (KPa), ($e_s - e_a$) = saturation vapour pressure deficit (KPa), $\Delta$ = slope vapour pressure curve (KPa$^0$C$^{-1}$),
$\gamma$ = psychrometric constant (KPa$^0$C$^{-1}$)

Calculation of crop water requirement, $ET_c$, using CROPWAT model over the growing season was determined from $ET_0$ and $K_c$ as:

$$ET_c = K_c \times ET_0 \tag{5}$$

The net irrigation requirement ($IR_n$) has also been calculated using the CROPWAT computer program based on Allen *et al.* (1998) as:

$$IR_n = ET_c - P_e \tag{6}$$

where $ET_c$ is the crop water requirement in mm and $P_e$ is the effective rainfall in mm.
The effective rainfall $P_e$ was also estimated using the method given by Allen *et al.* (1998) as:

$$P_e = 0.6 \text{ x } P\text{-}10 \text{ for } P_{month} \leq 70 \text{ mm} \tag{7}$$

$$P_e = 0.8 \text{ x } P\text{-}24 \text{ for } P_{month} > 70 \text{ mm} \tag{7$^b$}$$

where P stands for precipitation (mm)
Gross irrigation water requirement ($I_g$) can be calculated by

$$I_g = \frac{\text{net irrigation water requirement } (IR_n)}{\textit{water application efficiency } (E_a)} \quad \textbf{(8)}$$

The application time (min) required to deliver the desired depth of water into each furrow was calculated using the equation:

$$t = \frac{I_g \times w \times l}{6Q} \quad \textbf{(9)}$$

where l = furrow length (m), w = furrow spacing (m), and Q = flow rate (l/s).

### 2.10. Measurement of Water Discharge into Ditch

As method of irrigation was furrow irrigation, the water applied per each irrigation event was measured using three inch throat Parshall flume. The Parshall flume of 3 inch throat width and 2 m long was used for discharge measurement in a ditch during the research. It was positioned at least at the distance of 3m from the nearby plot (straight 3 m for water to attain steady flow before and after the flume) for all the replication sites. The time to meet the required depth was then monitored by stopwatch. The flume was first calibrated, and is almost similar with the standard table on FAO irrigation and drainage bullet no.56. Three different discharges were measured for all replications: at heads of 2.872, 3.532 and 4.239 l/s each passed at 7, 8 and 9 centimeters respectively.

### 2.11. Irrigation Scheduling by CROPWAT and WFD

CROPWAT model version 8.0 (a computer program) which considers climate, soil infiltration, crop characteristics ($K_c$ values, rooting depth, length of growth period), allowable depletion level and date of planting of the crop, was used as a technique of irrigation scheduling. The allowable soil moisture depletion for the crop was used as 25% (Doorenbos and Kassam, 1996). For the wetting front detector, the irrigation interval was monitored by the pop up response of the tool. Irrigation interval (in days) is guided by susceptibility of the crop to water shortage, and was conducted from CROPWAT model prediction result, WFD response, as well as the farmers practice in this study. It was computed from the required depth and crop water use rate as:

$$f = \frac{Z_{req}}{ET_c} \quad \textbf{(10)}$$

where $f$ = irrigation interval in days,
$Z_{req}$ = required depth of water applied (mm) and
$ET_c$ = crop water requirement (mm/day)

### 2.12. Yield and Yield Components

The amount of pepper fruits produced were collected from central ridges only for the sake of avoiding boarder effects to observe the effect of treatments on crop yield. Both marketable and unmarketable yields were collected and analyzed. Pepper was harvested twice only because of the commencement of rainfall during maturity. Weight of fresh fruits harvested at both harvesting periods from the central rows was recorded; the data recorded during both times were then summed up for estimation of yield per hectare.

### 2.13. Water Productivity

Water productivity was estimated in terms of crop water use efficiency (CWUE), irrigation water use efficiency (IWUE) and economic water productivity (EWP).

### 2.14. Data Analysis

To evaluate the water management techniques identified in this study, a number of direct and indirect performance evaluations had been made. These include computation of crop water requirement using the CROPWAT model, flow performance, efficiency and yield assessment.

The data were subjected to analysis of variance (ANOVA) using Tukey's Highly Significant Difference of Statistical Analysis Software (SAS) 9.0. Significant differences between treatment means were separated using the Fisher's LSD test at the level of significance of $P < 0.05$ following Gomez and Gomez (1984) procedure.

## 3. Result and discussion

### 3.1. Soil Characterization

Soil samples (before planting) were collected, its physico-chemical properties were analyzed before planting and after harvest, and the results are presented in Tables 1, 2 and 3.

**Before planting**

Table 1. Soil physical properties (before planting)

| Code | Depth (cm) | FC (%) | PWP (%) | BD ($g/cm^3$) | TAW (%) | Sand | Clay | Silt | Texture |
|---|---|---|---|---|---|---|---|---|---|
| 1701HH | 0-30 | 21.76 | 12.27 | 1.29 | 122.42 | 39.95 | 24.85 | 35.20 | L |
| | 30-60 | 25.82 | 14.39 | 1.31 | 149.73 | 38.03 | 26.70 | 35.27 | |
| 1703AD | 0-30 | 34.28 | 20.69 | 1.40 | 190.23 | 57.78 | 14.78 | 27.44 | SL |
| | 30-60 | 27.63 | 20.89 | 1.46 | 98.40 | 55.86 | 16.63 | 27.51 | |
| 1705AG | 0-30 | 39.52 | 24.85 | 1.37 | 200.91 | 75.42 | 8.19 | 16.39 | SL |
| | 30-60 | 23.4 | 22.36 | 1.49 | 15.50 | 73.50 | 10.04 | 16.46 | |
| 1706AT | 0-30 | 22.11 | 11.68 | 1.39 | 144.98 | 65.07 | 12.33 | 22.60 | SL |
| | 30-60 | 22.59 | 13.88 | 1.52 | 132.39 | 63.15 | 14.18 | 22.67 | |
| 1707TM | 0-30 | 23.66 | 13.33 | 1.29 | 133.26 | 67.10 | 10.28 | 22.62 | SL |
| | 30-60 | 28.17 | 15.71 | 1.40 | 174.44 | 65.18 | 12.13 | 22.69 | |
| 1708BU | 0-30 | 42.52 | 24.69 | 1.28 | 228.22 | 69.19 | 8.21 | 22.60 | SL |
| | 30-60 | 28.44 | 23.37 | 1.36 | 68.95 | 67.27 | 10.06 | 22.67 | |
| 1713BB | 0-30 | 39.99 | 26.14 | 1.31 | 181.44 | 47.50 | 25.20 | 27.30 | SCL |
| | 30-60 | 29.74 | 23.88 | 1.46 | 85.56 | 45.58 | 27.05 | 27.37 | |

☞ L = Loam, SL = Sandy Loam, SCL = Sandy Clay Loam, FC(%)= Field Capacity, PWP(%) = Permanent Wilting Point, BD = Bulk Density, TAW = Total Available Water (%)

**Particle size distribution:** According to USDA (1994) soil textural classification, the three major soil classes identified were loam, sandy loam and sandy clay loam. More often, but small amount of irrigation is required for such type of soil (FAO, 1996).

**Soil bulk density and moisture contents at FC and PWP**

The soil bulk densities of the study sites varied from 1.28 to 1.52 $g/cm^3$, within the range of ideal bulk densities for plant growth (USDA, 2008). The total available soil water (TAW) for each fields were also computed from bulk density, FC and PWP following equation 1, and generally, the TAW were higher for the upper 30 cm depth.

**$P^H$ and organic matter contents**

Table 2. Chemical properties of soil before planting

| Code | Date | $p^H$ ($H_2O$) 1:2.5 | EC (*mS/cm*) | OM (%) | CEC (*meq/100*) | Sum of cations | ESP (%) |
|---|---|---|---|---|---|---|---|
| AG | 29/12/2015 | 9.41 | 0.08 | 4.40 | 21.81 | 21.42 | 23.47 |
| HH | 29/12/2016 | 9.41 | 0.08 | 4.40 | 21.81 | 21.42 | 23.47 |
| BU | 29/12/2017 | 9.07 | 0.13 | 3.03 | 20.97 | 20.75 | 26.38 |
| AS | 29/12/2018 | 9.07 | 0.13 | 3.03 | 20.97 | 20.75 | 26.38 |
| AM | 29/12/2019 | 9.00 | 0.12 | 3.69 | 54.30 | 51.95 | 16.00 |
| MB | 29/12/2020 | 8.83 | 0.30 | 3.91 | 39.57 | 39.04 | 19.32 |
| FT | 29/12/2021 | 9.12 | 0.10 | 2.47 | 23.80 | 23.71 | 21.15 |

➤ *EC (mS/cm) (1:2.5), O.M (%), CEC (meq/100 gm of soil), ESP % Sum of Cations (meq/100gm of soil)*

It is observed from Table 2 that the soil pH varied from 8.83 to 9.41 which were out of preferable range (strongly alkaline according to the rating given by Tekalign and Haque, 1991) for pepper (Doorenbos and Kassam, 1996; Olani and Fikre, 2010). This would be the case for lower water productivity especially for pepper. Generally, such problematic soils need to be reclaimed before using for production. The organic matter (O.M) content also varied between 2.47 to 4.4% (in the range of very low to low according to Landon (2014) rating), that which is inadequate. The electrical conductivity (EC) values ranged from 0.08 to 0.13 mS/cm. These values were safe for the crop that the yield reduction of pepper ranges between 2.2 to 8.5 mS/cm (Doorenbos and Kassam, 1996; Andreas and Karen, 2002).

**After crop harvest**

Table 3. Chemical properties of soil after harvest

| **Code** | **Date** | **P^H^ (H₂O)** 1:2.5 | **EC** (*mS/cm*) | **OM** (%) | **CEC** *(meq/100)* | **Sum of cations** | **ESP** (%) |
|---|---|---|---|---|---|---|---|
| AG_P_FP | 16/05/2016 | 9.05 | 0.17 | 0. 56 | 23.80 | 21.31 | 15.93 |
| AG_P_WFD | 16/05/2016 | 8.78 | 0.15 | 0. 62 | 27.88 | 23.54 | 15.08 |
| AG_P_CWR | 16/05/2016 | 8.02 | 0.13 | 0.60 | 29.04 | 22.48 | 14.28 |
| HH_P_FP | 16/05/2016 | 8.75 | 0.43 | 0.49 | 16.79 | 12.20 | 16.05 |
| HH_P_WFD | 16/05/2016 | 8.62 | 0.20 | 0.58 | 25.68 | 20.01 | 15.34 |
| HH_P_CWR | 16/05/2016 | 8.42 | 0.20 | 0.76 | 25.91 | 16.32 | 14.70 |
| AS_P_ FP | 16/05/2016 | 8.45 | 0.92 | 0.94 | 25.69 | 23.00 | 12.71 |
| AS_P_WFD | 16/05/2016 | 8.37 | 0.45 | 1.07 | 26.07 | 23.89 | 6.97 |
| AS_P_CWR | 16/05/2016 | 8.12 | 0.52 | 1.10 | 26.11 | 24.01 | 6.28 |
| AM_P_ FP | 16/05/2016 | 8.65 | 0.19 | 0.98 | 20.04 | 17.13 | 15.44 |
| AM_P_WFD | 16/05/2016 | 8.05 | 0.19 | 1.01 | 30.12 | 25.19 | 6.58 |
| AM_P_CWR | 16/05/2016 | 7.98 | 0.17 | 1.05 | 25.13 | 26.21 | 6.42 |

P = pepper, FP, WFD and CWR are the irrigation water optimization techniques evaluated;
EC (mS/cm), O.M (%), CEC *(meq/100 gm soil)* sum of cations (*meq/100 gm soil*).

It can be generalized from Table 3 that soil test results after crop harvest revealed that soil pH, EC and ESP all were relatively lower under CWR followed by the WFD than the FP. The reverse holds true for organic matter (O.M) content, cation exchange capacity (CEC) and sum of cations.

Generally, it is conclusive from the pH value of the soil that it was decreased from 'strongly alkaline' before planting to 'moderately alkaline' after crop harvest according to the rating made by Tekalign and Haque (1991). Higher pH was observed under FP followed by the WFD in line with the amount of applied water. Possible reason may be leaching of basic cations.

According to Landon (2014) rating, organic matter (O.M) content was in the range of 'very low' to 'low' before planting and totally reduced to 'very low' at all after crop harvest. It was relatively better under the CWR followed by the WFD than the FP. The electrical conductivity (EC) increased from before planting to after harvest (Tables 2 and 3) under both crops. EC under the FP for both crops was the maximum whereas it was the minimum under CWR; irrigation water depth has direct relation with EC. The values of sum of cations and CEC were increased from before planting to after harvest, as well as farmer practice through WFD to the crop water requirement.

CEC was in the range of moderate to very high before planting which becomes moderate to high after crop harvest based on the rating of CEC given by Landon (2014). CEC was generally increased from before planting to after harvest; the minimum was observed under CWR for both crops while its maximum was observed under farmer practice. Possible reason may be irrigation water quality.

**Infiltration capacity**

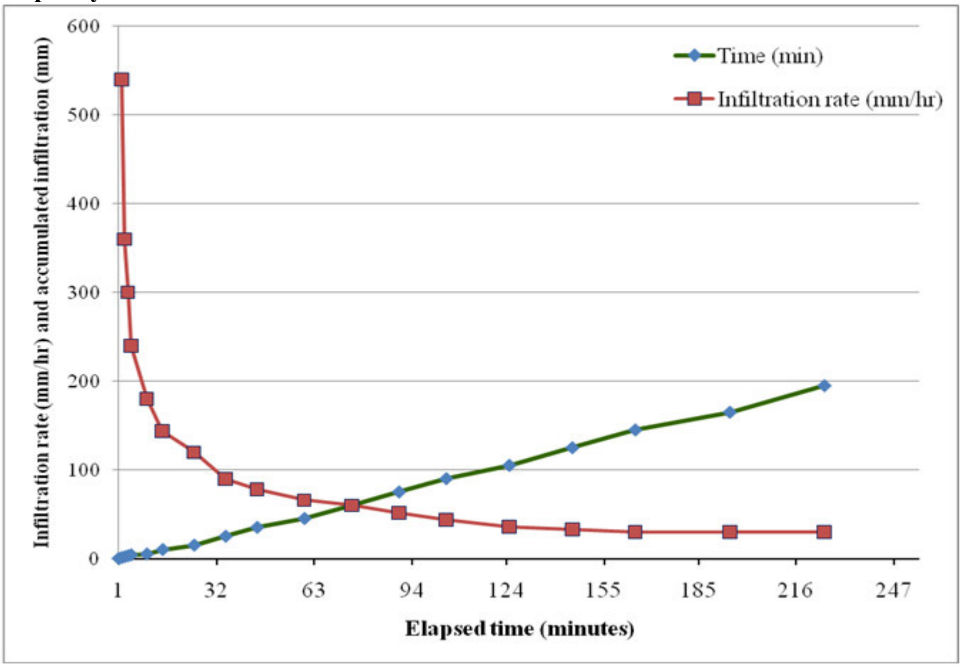


Figure 4. Soil infiltration rate

Result from Figure 4 indicated that the soil had initially higher infiltration rate (540 mm/hr), gradually decreasing and attained the basic infiltration rate (30 mm/hr) after about 2 hours and 25 minutes. The result has shown that it was consistent with the report of Scherer *et al*. (1996) that the basic infiltration rate of sandy loam soil is in the range of 20 to 30 mm/hr and for loam is also 10 to 20 mm/hr. The soil being sandy loam/loam (Table 1) and moderately high infiltration rate had therefore, low water storage capacity. As a result, they need frequent but small irrigation applications (FAO, 1989; Scherer *et al*., 1996).

### 3.2. Water Applied through the Water Management Techniques

Table 4. Summary of average water applied (mm) to Pepper

| Irrigation event | Amount of water applied (mm) | | |
|---|---|---|---|
| | CWR | WFD | FP |
| 1 | 14.68 | 34.88 | 37.27 |
| 2 | 7.59 | 22.94 | 24.28 |
| 3 | 8.48 | 29.26 | 30.93 |
| 4 | 9.44 | 27.89 | 31.87 |
| 5 | 9.37 | 24.28 | 32.44 |
| 6 | 10.20 | 23.97 | 29.55 |
| 7 | 13.97 | 22.66 | 28.12 |
| 8 | 11.28 | 21.48 | 31.88 |
| 9 | 14.16 | 21.65 | 34.10 |
| 10 | 15.67 | 22.84 | 33.94 |
| 11 | 17.17 | 22.39 | 35.79 |
| 12 | 22.14 | 22.28 | 34.74 |
| 13 | 22.75 | 22.51 | 34.57 |
| 14 | 28.26 | 22.58 | 82.42 |
| 15 | 76.57 | 98.86 | 68.01 |
| 16 | 135.54 | 123.25 | 124.09 |
| 17 | 21.36 | 23.74 | 173.00 |
| 18 | 173.00 | 173.00 | |
| **Total** | **404.47** | **534.86** | **638.1** |

It is shown in Table 5 that, the amount of irrigation water applied to the crop was generally ascending linearly with the crop growth stage under the CWR, while it was almost constant throughout all the irrigation events under both the WFD and FP. The total amount of water applied through crop water requirement (CWR) was lower followed by the WFD as compared to the farmer method (FP). The means of the amount of water applied during the cropping season through the three irrigation water management techniques were compared, and the results are presented in Table 6.

Table 5. The means of water applied ($m^3$) for *Pepper* crop (mean of 6 observations)

| Treatments | Pepper |
|---|---|
| CWR | 20.22[c] |
| WFD | 26.74[b] |
| FP | 31.91[a] |
| $LSD_{0.05}$ | 3.01 |
| CV | 8.90 |
| SE | 1.35 |

Result from Table 6 indicated that there was a significant difference among the irrigation water management technologies for the amount of irrigation water applied. The mean volumes of irrigation water saved by using the CWR were considerably higher (about 37%) followed by the WFD (16%) than the farmer practice. This implies that the water saved by the CWR technique could irrigate more area than the WFD and, the WFD in turn could irrigate more area than farmer method that would provide additional crop production. Moreover, volume of water applied through CWR and WFD were more or less similar with amount of water required for the crops as reported in the studies carried out by Doorenbos and Kassam (1996)

### 3.3. Efficiencies of Irrigation Water Optimization Techniques

The most common effectiveness parameters used to judge the performance of an irrigation water management technologies: uniformity, efficiency and adequacy (James, 1988) were used to evaluate. Application and storage efficiencies along with deep percolation fractions considered and evaluated on the field. Soil moisture data before and 24 hours after irrigation (when it ideally attained the field capacity) was taken to determine these effectiveness parameters and the obtained results are presented in Table 7.

Table 6. Effect of irrigation water management on $E_a$ (%), $D_p$ (%) and $E_r$ (%)

| **Irrigation management** | **$E_a$[p]** | **$D_p$[p]** | **$E_r$[p]** |
|---|---|---|---|
| CWR | 59.06[a] | 40.94[c] | 65.09[a] |
| WFD | 53.78[b] | 46.12[b] | 59.78[b] |
| FP | 49.26[c] | 50.74[a] | 52.67[c] |
| CV | 4.49 | 5.28 | 4.4 |
| $LSD_{0.05}$ | 3.12 | 3.12 | 3.8 |
| SE | 1.4 | 1.4 | 1.5 |

$E_a$, $D_p$ and $E_r$ are application, deep percolation and storage efficiencies respectively

**Application efficiency:** From the results presented in Table 7, one can clearly see that there is a significant difference among water application efficiencies of all water management techniques at $P<0.05$ that the $E_a$ of WFD technique (53.78) is better than that of FP (49.26) whereas that of the CWR (59.06) is the best relative to those other water optimization techniques. The results obtained from CWR are consistent with the end dyked furrow irrigation application efficiency (Zerihun *et al*., 1997; FAO, 1989).

**Deep percolation:** Irrigation water losses from the field occur as deep percolation (applied depth is greater than required depth), field tail water and evapotranspiration. Runoff losses cannot be significant if tail water is controlled and reused. The evapotranspiration loss was insignificantly different among treatments. Efficient furrow irrigation requires reducing the two major irrigation water losses – deep percolation and surface runoff.

No tail water observed during all irrigation events since the fields were totally end dyked at each furrow. This means that the water applied to the field was mainly subdivided into the water stored in the root zone which is beneficially used by the crops and the rest percolated as $D_p$.

The deep percolation fractions presented in Table 7 were significantly different among treatments that the maximum value (50.76) is observed at farmer's practice which is wastage in the point of view of irrigation water savings. This is also consistent with Kassa (2001). Under both crops, the desirable result – minimum $D_p$ value (40.94) – is observed by the CWR followed by the WFD (46.12).

**Storage efficiency**

The results (from Table 7) show that significant difference ($p<0.05$) among irrigation water management techniques observed. The CWR has relatively better storage efficiencies (65.09) followed by the WFD (59.78) than the FP (52.67). Consequently, the crop under the FP didn't get plenty of moisture for its growth and development. As a result, their yield reduction observed.

### 3.4. Crop Yield Characterization

The marketable yields were subjectively determined based on quality ratings. The color of the fresh fruits, shininess, presence of surface defects due to insect or disease damage, fruit firmness and size were taken as visual parameters for marketable rating. Those fruits preferred by consumers based on the above criteria were taken as marketable and those that did not were discarded after weighing and considered as unmarketable.

Table 8. Impact of irrigation water management on yields of *Pepper*

| Treatment | Marketable yield (t/ha) | Unmarketable yield (t/ha) |
|---|---|---|
| CWR | 1.36[a] | 0.32[a] |
| WFD | 1.63[a] | 0.38[a] |
| FP | 0.96[b] | 0.44[a] |
| $LSD_{0.05}$ | 0.29 | 0.15 |
| CV | 16.96 | 31.01 |
| SE | 0.13 | 0.07 |

Results from Table 8 revealed that there was a significant difference ($p<0.05$) among treatments for marketable yields. Marketable yield has no significant difference at $p=0.05$ between CWR (1.36 t/ha) and WFD (1.63t/ha) but FP (0.96 t/ha). The yield results were consistent with the significant improvements in yields that have been associated with CWR (Doorenbos and Kassam, 1996) and this scenario may be true for WFD. However, the highest marketable yield from report of Amare (2013) was 1.91 t/ha.

### 3.5. Water Use Efficiencies and Water Productivity

Table 9. Effect of irrigation water management on WUE and WP

| Irrigation management | **IWUE** (*Kg/ha/mm*) | **CWUE** | **WP** (Kg/m$^3$) |
|---|---|---|---|
| CWR | 3.36[a] | 5.26[a] | 0.34[a] |
| WFD | 3.08[a] | 2.56[b] | 0.31[a] |
| FP | 1.52[b] | 1.30[c] | 0.15[b] |
| CV | 0.60 | 0.83 | 0.06 |
| $LSD_{0.05}$ | 17. 67 | 21.27 | 17.55 |
| SE | 0.27 | 0.73 | 0.03 |

The efficiency of irrigation water shown by both CWR and WFD statistically have no significant difference ($P=0.05$), showing desirable results than the Farmer Method. However, the CWR has better CWUE than the WFD whilst FP was the least.

The WFD was equally important as CWR for water productivity. The least water productivity (0.15 kg/m$^3$) was observed from the FP. Inconsistent water productivity values were observed: it is much lower than that of Doorenbos and Kassam (1996). The possible reason would be the picking round that it was picked only twice although several picking is possible. Besides, the soil was problematic, need reclamation before use for production.

### 3.6. Irrigation Water Saving

Results obtained from Table 9 show that the CWR technique lead to lesser water input yet was still able to generate yield comparable to both WFD and FP.

More precisely, this study illustrates that there was a significant difference between the water used in the CWR, WFD and Farmer Practice (FP). In comparison with FP, CWR saved irrigation water by 37%. The WFD technology also saved the irrigation water by about 16% than the farmer irrigation method. This amount of irrigation water can irrigate more area and provide additional crop production.

In the point of view of soil salinity, the CWR technique was also relatively safe method followed by the WFD, whereas the farmer irrigation practice was the poor method. It can also be generalized from the results that saving irrigation water do not only irrigate more area for additional crops, but also sustain irrigation.

## 4. Conclusion and recommendation

### 4.1. Conclusion

In this study, an attempt was made to evaluate three water management techniques – CWR, WFD and FP – in the rift valley of East Shoa zone for pepper production. Application efficiency, adequacy, UCC of applied water, water use efficiency, water productivity and water savings were used as indicator to undertake the evaluation.

Performance indices corresponding to each of those terms were computed in terms of perceived requirement for specific irrigation water management techniques. On farm measurement was made for infiltration test. Soil moisture before and after irrigation were carried out to compute target indicators. The experiment was designed in RCBD with six replications for pepper. Tukey's LSD test was used to separate the mean differences statistically.

The results generally indicate that the water application and storage efficiencies of the techniques were significantly different. Yield obtained from WFD technique was not significantly different from CWR technique. Whilst yield from FP was significantly lower. Similarly for onion, the yield obtained varied considerably among the tested techniques of on farm water optimization and again better yield was collected from CWR followed by WFD while the minimum yield was from the FP. Similar trend was observed for the different indicators assessed in this study. Results from table 8 shown that both Christiansen coefficients of uniformity as well as irrigation scheduling of the irrigation water management techniques were not different at $p \leq 0.05$.

Results obtained from this study show that the CWR technique lead to lesser water input yet was still able to generate pepper yield comparable to both WFD and FP. Yields of pepper under the CWR were statistically similar to these under the WFD. The CWR approach saved water by about 37% higher than FP under pepper while the WFD saved 16%. On an average, about 50.74% of the water applied was percolated below the root zone and not available to the crop production under FP.

The $D_p$ loss for CRW was less followed by the WFD. Implication of $D_p$ loss – wastage of irrigation water via over irrigation may aggravate waterlogging and salinity problems, raise ground water table and leach valuable nutrients below crops root zone (Walker, 1989).

IWUE also were observed to be higher under CWR followed by WFD for onion, while it was equally important under pepper. The $E_r$ – which can be beneficially used by the crop – of CWR was also higher followed by the WFD. As a result, yield of the crops from the CWR exceeds both techniques. Moreover, the $D_p$ loss is considerably higher in FP than WFD and CWR and similar trend was observed for IWUE. Based on this study, CWR technique appears to be a promising alternative for water optimization.

### 4.2. Recommendations

- It is advisable for irrigators to determine irrigation water requirement of their crops other than applying irrigation water from their experience.
- Irrigation water managers should follow the irrigation water optimization tools in order to improve the water use efficiency and solve conflicts between head and tail water users.
- It is better to repeat this experiment, monitoring soil moisture by in-situ soil moisture profiles like TDR or neutron probe.

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